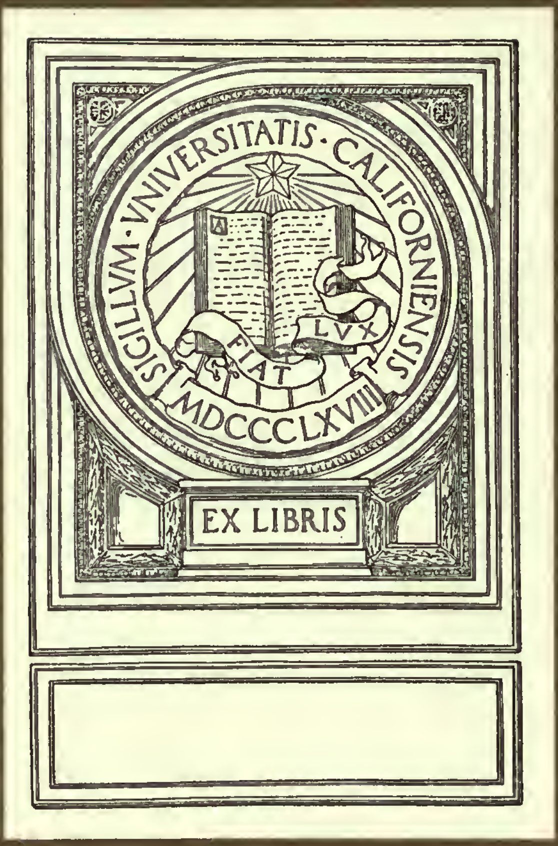
HA
29
B5

UC-NRLF
$C 20 313

YE 12176



SIGILLVM · VNIVERSITATIS · CALIFORNIENSIS
FIAT LVX
MDCCCLXVIII
EX LIBRIS

Probable error in field experimentation with Hevea

BY

O. F. BISHOP, J. GRANTHAM AND M. D. KNAPP

(with Summary).

De waarschijnlijke fout bij veldproeven met Hevea

DOOR

O. F. BISHOP, J. GRANTHAM EN M. D. KNAPP

(Résumé).

Overgedrukt uit het Archief voor de Rubbercultuur,
Jaargang I No. 5 (November 1917).

Aangeboden door de
Hollandsch-Amerikaansche Plantage Maatschappij.
Kisaran, 1 Februari 1918.

HA29
B5

UNIV. OF
CALIFORNIA

PROBABLE ERROR IN FIELD EXPERIMENTATION WITH HEVEA.

O. F. BISHOP, J. GRANTHAM AND M. D. KNAPP

I.

Introduction.

Many of the published results of experiments with Hevea are so conflicting that they are of very little value as a basis for practical operations in deciding between two methods of treatment where only a small difference at the most can be expected. When small differences are obtained it becomes particularly important to be certain that they are due to treatment if favorable financial results are to be secured in practical application.

In April 1916, Coombs and Grantham published a paper in the *Agricultural Bulletin of the Federated Malay States* on "Field Experiments and the Interpretation of Their Results". The basis of this article was a paper entitled "The Interpretation of Experimental Results" by Wood and Stratton published in 1909 in the *Journal of Agricultural Science*, Vol. III, part IV. The method has been also briefly referred to in an article entitled "The Art of Rubber Experiment" by Petch, *Tropical Agriculturist*, February 1915.

We embody below certain conclusions which may be deduced from these papers:

1. The results of a single experiment are very often misleading.
2. In interpreting experimental results the need of attempting to allow for errors that are present in all field experimentation work. Such errors are those of manipulation, difference of site (meaning the intrinsic properties of the soil, its condition and situation), and variations among the individuals.
3. By the application of certain mathematical methods, one of which is "the method of least squares", to the results of experiments, a single numerical expression, usually referred to as the „probable error", may be calculated for all errors. With its aid results may be interpreted with more accuracy. The probable error is a measure of the reliability of a result, and is such that the chances are even that the difference between

M43625

any single result taken at random and the mean or average of the results will be greater or less than the amount of the probable error.

4. Increasing the size of the plot, beyond a certain limit, does not decrease the probable error. When this limit is reached the error can be reduced by duplication only of experiments.

5. Using the „method of least squares", the probable error of any one result from the mean of several is found from the formula:

$$\text{Probable error} = 0.67 \sqrt{\frac{\Sigma d^2}{n-1}}$$

where d equals the difference between a result and the mean or average of all the results.
Σd^2 „ the sum of the squares of the differences.
n „ the number of results.

This may be made clearer by its application below to the yields, over a two-year period from 78 plots.

Table 1.

Plot No.	% yield	d	d²
1	97.7	2.3	5.29
2	91.5	8.5	72.25
3	110.8	10.8	116.64
4	98.6	1.4	4.96
5	92.3	7.7	59.29
6	108.8	8.8	77.44
7	91.8	8.2	67.24
8	105.4	5.4	29.16
9	103.0	3.0	9.00
10	82.7	17.3	299.29
11	107.8	7.8	60.84
12	109.8	9.8	96.04
13	101.3	1.3	1.69
14	88.1	11.9	141.61
15	110.5	10.5	110.25
16	104.5	4.5	20.25
17	84.4	15.6	243.36
18	111.6	11.6	134.56
19	102.6	2.6	6.76
20	95.1	4.9	24.01
21	102.3	2.3	5.29
22	93.5	6.5	42.25
23	88.7	11.3	127.69
24	117.3	17.3	299.29
25	104.1	4.1	16.81
26	85.3	14.7	216.09
27	110.0	10.0	100.00
28	92.8	7.2	51.84
29	93.5	6.5	42.25
30	113.7	13.7	187.69

Plot No.	% yield	d	d^2
31	117.1	17.1	292.41
32	98.7	1.3	1.69
33	84.2	15.8	249.64
34	98.6	1.4	1.96
35	91.2	8.8	77.44
36	110.7	10.7	114.49
37	106.1	6.1	37.21
38	83.2	16.8	282.24
39	110.5	10.5	110.25
40	94.1	5.9	34.81
41	72.8	27.2	739.84
42	133.1	33.1	1095.61
43	102.1	2.1	4.41
44	105.5	5.5	30.25
45	92.7	7.3	53.29
46	106.0	6.0	36.00
47	79.0	21.0	441.00
48	115.5	15.5	240.25
49	102.8	2.8	7.84
50	100.8	.8	6.64
51	96.0	4.0	16.00
52	89.0	11.0	121.00
53	95.5	4.5	20.25
54	115.4	15.4	237.16
55	83.0	17 0	289.00
56	96.4	3.6	12.96
57	120.1	20.1	404.01
58	96.1	3.9	15.21
59	109.3	9.3	86.49
60	94.9	5.1	26.01
61	76.8	23.2	538.24
62	107.2	7.2	51.84
63	115.8	15.8	249.64
64	88.9	11.1	123.21
65	103.0	3.0	9.00
66	107.9	7.9	62.41
67	93.2	6.8	46.24
68	100.0	.0	.00
69	106 6	6.6	43.56
70	90.7	9.3	86.49
71	101.0	1.0	1.00
72	108 6	8.6	73.96
73	90.1	9.9	98.01
74	99.2	.8	.64
75	111.0	11.0	121.00
76	95.8	4.2	17.64
77	98.4	1.6	2.56
78	105.9	5.9	34.81
Average = 100			$d^2 = 9308.74$

$$p.\,e. = .67\sqrt{\frac{\Sigma d^2}{n-1}}$$

$$= .67\sqrt{\frac{9308.74}{77}}$$

= 7.36 or approximately 7.5.

As will be seen below, the probable error is usually expressed as a percentage of the mean. In this example, as the mean is 100, the probable error obtained is also the per cent probable error.

The mean is found by dividing the sum total of the results by the number of results.

Where large numbers of results are to be combined, the results may be grouped into classes to facilitate the work, in which case the mean is found by the formula: $A = \frac{\Sigma(V \times f)}{n}$

where

A equals mean or average
V „ the magnitude of any class
f „ the number of results in a class, i. e., the frequency of the class.
$\Sigma(V \times f)$ „ the sum of $(V \times f)$.
n „ the total number of results or variates.

and the formula for probable error becomes p. e. $= 0.67 \sqrt{\frac{\Sigma(d^2 \times f)}{n-1}}$.

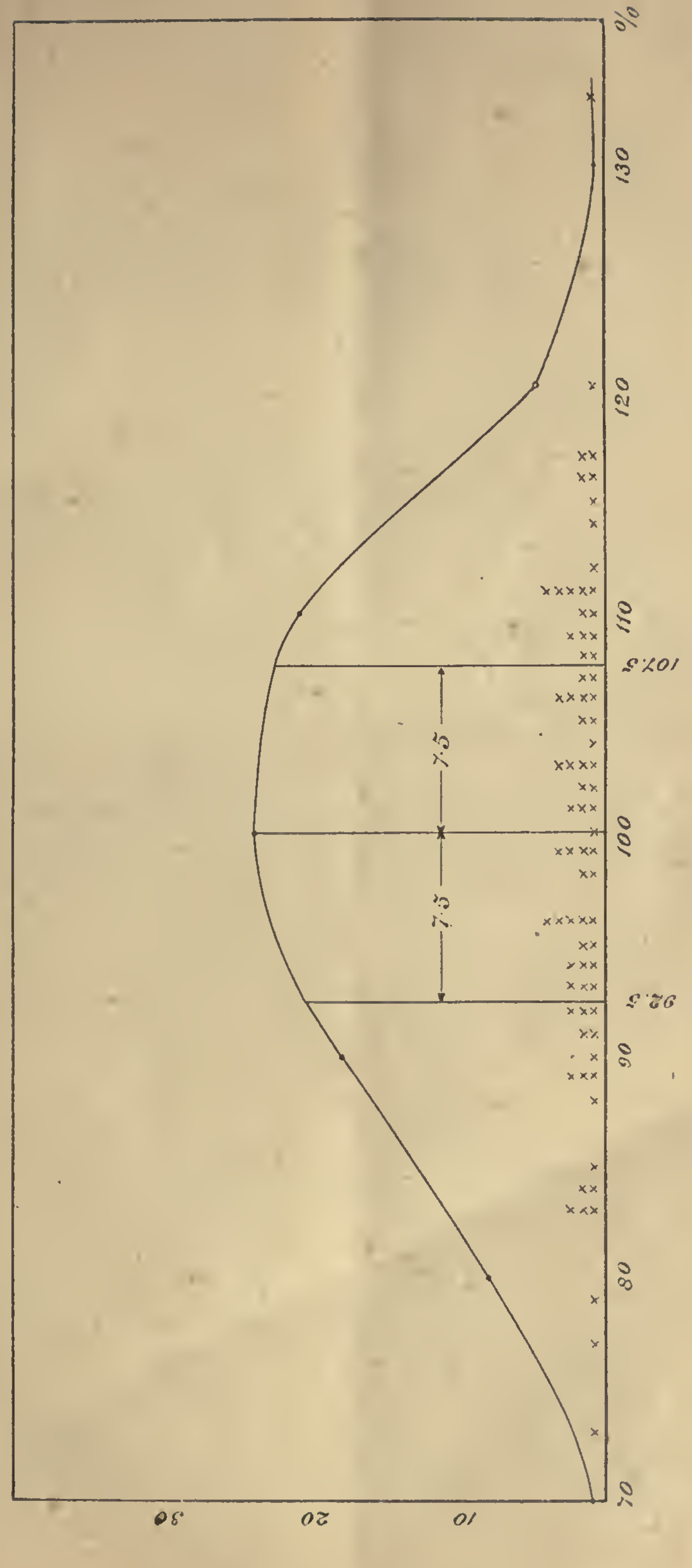
In this case d is the difference between a class and the mean. For an application of this formula, see table XI.

The probable error equation may be applied to any results which, when plotted, give a symmetrical frequency curve. This may be best explained by an example from practice. In plate 1 the results in per cent of the 78 plots are plotted. This curve conforms in general to a symmetrical frequency curve. The highest point of the curve is at 100, or the average, and the number of results on each side of this is as nearly equal (39—38) and as uniformly distributed as could be expected.

Therefore the "method of least squares" applies.

To show the relation between the "method of least squares" and the symmetrical frequency curve, it is necessary to calculate the probable error for the yields of the above results; this is found to be 7.5 % (see table 1). If lines are drawn on each side of the mean, and at a distance from it corresponding to the probable error, that is at 92.5 and 107.5, equal numbers of results should fall inside and outside these limits. It is found that 38 results fall inside and 40 outside. This is a sufficiently close approximation to the theoretical expectation. It follows that if any plot receives special treatment and differs from the mean by 7.5, the chances are even that the treatment has or has not an effect.

In rubber experiments the object is usually to ascertain the effect of a factor present in one instance and absent in another, in which case we have to compare two results with each other and not one result with a mean.


70
80
90
92.5
100
107.5
110
120
130
%
7.5
7.5
10
20
30

Each of these results is subject to a probable error. Their difference is therefore liable to a greater probable error than either. This probable error is obtained from the formula:

p.e. of difference $= \sqrt{E_1^2 + E_2^2}$ where E_1 is the probable error of one result and E_2 the probable error of the other result.

Usually the two results will be subject to the same probable error, when the probable error of the difference becomes equal to $\sqrt{2 \times (\text{p.e. of one result})^2}$ or $\sqrt{2} \times$ p.e. of one result.

For example, in table I the probable error of any result is 7.5, and the probable error of the difference of any two results is $7.5 \times \sqrt{2} = 10.57$. If there is a factor present in one plot and absent in the other, and the difference between the two plots is 10.57, it is even chances or odds that the factor may or may not have had an influence. As the difference increases, the chances or odds that the factor has had an influence rapidly increase, and in accordance with an equation derived from the frequency curve. This constant relationship between odds and difference is shown in table II for two cases:

1st. Where it is uncertain whether the difference will be an increase or a decrease, i.e., the difference may be in either direction.

2nd. Where it is expected that the difference will be either an increase or a decrease, i.e., a difference in one direction only.

Table II.

*) Difference between two results divided by the probable error of their difference.	Difference between two results with a common probable error divided by the probable error of one result.	Odds in favor of at least part of the difference being due to the factor.	
		Odds where a difference may be obtained in either direction.	Odds where a difference is to be expected in one direction only.
1.00	1.41	1 : 1	3 : 1
1.25	1.76	3 : 2	4 : 1
1.44	2.03	2 : 1	5 : 1
1.58	2.23	5 : 2	6 : 1
1.71	2.41	3 : 1	7 : 1
1.81	2.55	7 : 2	8 : 1
1.90	2.68	4 : 1	9 : 1
2.00	2.83	9 : 2	10 : 1
2.48	3.50	10 : 1	20 : 1
2.70	3.81	15 : 1	30 : 1
2.89	4.07	20 : 1	40 : 1
3.00	4.24	22 : 1	44 : 1
3.03	4.28	25 : 1	50 : 1
3.20	4.51	30 : 1	60 : 1
3.44	4.85	50 : 1	100 : 1
3.54	5.00	70 : 1	140 : 1

---

*) When the probable error is expressed in per cent, either the probable error must be transformed into pounds (or other unit) or the difference into per cent. In order to express probable error in pounds, or the difference in per cent, the result taken as

Suppose there is a difference of 15 $^0/_0$ between the results of two tapping experiments, each having a probable error of 7.5 $^0/_0$, then the probable error of their difference is 7.5 $^0/_0 \times \sqrt{2} = 10.57$ $^0/_0$. The quotient, as required by column 1 of table II, is 1.41; the nearest number to this in the column is 1.44. Hence the odds in favour of part of the difference being due to the systems are respectively 5 to 1 and 2 to 1 according as the difference may be expected in one or both directions.

Since small increments above the difference corresponding to odds of 30 to 1 cause an enormous increase in the odds, it is generally accepted that odds of 30 to 1 give practical certainty.

Definite conclusions should not be drawn where the actual difference is less than that corresponding to odds of 30 to 1; where it is higher, only the amount by which it exceeds the difference corresponding to odds of 30 to 1 may be ascribed with certainty to treatment.

A greater amount may, however, be due to treatment, since the normal variation will seldom reach the possible maximum.

Where there are a number of duplications of an experiment, the average of all the results is clearly more accurate than a single result from one experiment.

The probable error of an average is the probable error of one result divided by the square root of the number of results which are averaged.

The formula is:

$$\text{p. e. of average} = \frac{\text{p. e. of one result}}{\sqrt{n}}$$

For example the probable error of the average of the 78 results is $\frac{7.5}{\sqrt{78}} = 0.85.$

The number of duplications, on which conclusions to any desired degree of precision many be based, can be ascertained by the application of the following formula:

$$\frac{\text{p. e. of one result}}{\sqrt{n}} = \frac{P}{M}$$

where P = the desired degree of precision in per cent.

M = the number of times the probable error required to give results of practical certainty (i. e. 30 to 1 odds); this is secured from table II.

n = the required number of duplications.

For example, if we wish to base conclusions on a difference in yields of 5 $^0/_0$ expected in one direction only, the probable error of a single result being 7.5 $^0/_0$, we calculate the necessary number of duplications thus:

---

control must be considered as approximating the theoretical mean. This introduces a small error which decreases as the number of duplications of an experiment increases.

$$\frac{\text{p. e.}}{\sqrt{n}} = \frac{P}{M}$$

$$\frac{7.5}{\sqrt{n}} = \frac{5}{3.8}$$

$$n = 32.49$$

Hence 33 duplications are necessary.

Where the probable error is 7.5 %, the number of duplications required to give odds of 30 to 1 with certain differences is shown in table III.

Table III.

Percentage difference in yield	Number of plots necessary	
	If difference may be obtained in either direction	If difference is expected in one direction only
1	1140	820
3	130	90
5	46	33
7.5	21	15
10	12	9
15	6	4
20	3	3
25	2	2
29	2	1
34	1	1
above 34	1	1

6. To obtain a number of results from which a probable error may be calculated, it is necessary to have either

(1) a large number of plots similarly treated, or

(2) a large number of groups of plots, all the individuals of a group, but not necessarily the groups themselves, having received identical treatment,

To the results of the plots in the first case the probable error formula may be applied directly.

In the second case the mean would be calculated for the results in each group, and the per cent relation of each plot of the group to this mean. The percents from all groups would then be combined to secure the probable error.

7. In order to arrive at the minimum size of plot, it would be necessary to have data from plots of various sizes. The preferable way of obtaining this is to secure results from a large number of small similar plots in one block which can be grouped to form larger plots. A series of probable errors corresponding to the sizes of the plots can be calculated, and the size obtained beyond which no reduction in probable error occurs.

II.

General Considerations on The Application of the Probable Error Method to Rubber.

In experiments with annual agricultural crops, WOOD and STRATTON found that the probable error between different plots, where the plot was 1/80 of an acre in size or larger, amounted to 5 % of the entire crop. These figures may not be applied to rubber, because:

1st. With rubber the variations in the yields of individuals are large and the number of individuals on any given area comparatively small. The minimum size of plot that will give the maximum reduction in probable error is, therefore, likely to be large compared with annual agricultural crops and must be established for rubber.

2nd. Variations in the quality of tapping are unavoidable and cause corresponding variations in yield. Variations due to the operations of collection do not obtain in gathering the yield of an annual crop from which it is always possible to obtain the total yield.

3rd. With yearly crops the probable error, when once determined, can be applied in general, because the entire life of the crop is dealt with and consequently the total effect of site on the crop is taken into consideration. In dealing with rubber a probable error over a period of one year takes into account the effect of site upon the crop at a certain age and under conditions existing at that age only. Local site conditions may cause similar areas to alter their relative yields with increasing age in such a manner as to cause a variation in probable error among the same plots at different ages. Further, if the probable error is known for a series of ages for one set of conditions of planting (such as spacing, holing, season of planting, material - used, etc.) on a given site, this may be incorrect for other planting conditions on a similar site and for the same planting conditions on a different site.

A probable error that would be standard for yield of rubber, should be worked out on a large number of plots in one block on a given site. As has been indicated the minimum size of plot, beyond which duplication only will reduce the probable error, is likely to be large. It may be expected that several hundred acres of the same age, planting, and treatment would be necessary to secure conclusive results. Such an area would unavoidably contain local variations of site, even though obviously abnormal plots were excluded.

A probable error so determined would hold in general for differing ages, soils, and plantings, provided the variations among the plots where it was applied were not greater than in the original experiment. It might be a larger probable error than was necessary in any given experiment, since on a comparatively small area, such as might be selected for a given experiment, less variation between plots might obtain.

In other cases the variations could be different from those in the original experiment.

This might happen in an empirical selection of experimental plots if poor judgment were used. In dealing with large areas, or areas of several acres, it is a comparatively easy matter to misjudge a plot and to include one outside of the range of the variations contained in the original experiment. This could be avoided somewhat by using other than an empirical selection of plots.

The average diameter of a plot might be used as an indication of the extent of variation (volume would be preferable but is difficult to secure). If then in the original experiment there was a maximum difference of 20 % in average diameters of the plots, we would have some justification in applying our probable error to plots where the difference of average diameters at the beginning of the experiment did not exceed 20 %.

Types of soil may exist on which variation increases with age on account of factors which become effective only as the rubber becomes older. Such factors are depth of soil, drainage, interference between roots and between crowns. Thus the probable error determined for a particular aged rubber on a particular type of soil may be incorrect for a different aged rubber, and for a different type of soil.

There are certain manipulation errors which tend to remain constant in amount and unaffected by an increase in yield. Consequently their percentage amount diminishes with increasing yield, that is in general with the age and size of the trees. Errors of this class are: reduced yield on rainy days, failure to tap deep enough at beginning and end of cut, differences in percentage of off-grades.

Available records show that the percentage probable error over monthly periods has increased when the yield has been greatly reduced. In an actual case this increase in probable error was from 3 to 13 per cent (see table IV).

In the probable error of field experimentation with rubber, there are then certain possible inaccuracies that would not be allowed for in applying a general probable error to experiments being conducted under conditions of age, site, and planting different from those in the plots where the original probable error was determined. The elimination of these possible inaccuracies would tend to a more correct interpretation of results.

If there are a large number of duplications of an experiment, a probable error for that particular experiment can be worked out from the results themselves, in which case the above inaccuracies do not arise.

A probable error for general application determined by the second method, namely, a combination of data from various sources, is liable to the same inaccuracies as that found by the first method. In addition, there is an error inherent in the method itself. Results from different sources will almost certainly have been derived from groups differently treated. To eliminate the effects of treatment, the average of each group is taken as 100, and each plot is expressed as a percentage of this. The average of the combined percentages will then be 100 also. An inaccuracy is introduced in all cases where the average of each group of plots would not have approximated to the average of all the plots had they all been similarly treated.

With duplicates the odds are 2 to 1 that one plot will lie on each side of the theoretical mean, which tends to make the average of the duplicates used approximate the theoretical mean. As the number of duplications increases, the chances rapidly increase that the mean obtained closely approximates the theoretical mean. The greater the number of duplications, the more we are justified in using the second or the „percentage of mean" method for securing our probable error. It does not, however, embody any natural variations which may occur between groups.

When this method is applied to the determination of a standard probable error the possible inaccuracy is, therefore, greater than in the first method.

In any one experiment with rubber when several duplications exist, or in any group of experiments where the number of experiments, but not necessarily of duplications, is large, this method can be applied with advantage to determine the probable error of the experiment itself. The inaccuracies discussed under the first method do not then arise, although the error due to natural variations between groups remains. This, however, diminishes as the number of available duplications increases.

III.

Parts I & II

Experimental.

Two experiments carried out on estates of the Holland . American Plantations Company, (H.A.P.M.), Kisaran, Asahan, Sumatra, are now described.

The first (A) is given as an actual example of the need of applying some method of allowing for normal variation and the advantages attending the use of the probable error method. The second (B) is an illustration of the application of the principles discussed in Parts I en II to the actual results of tapping experiments.

A. EXPERIMENTS ON AJER POETIH ESTATE.

The results of this experiment show the unavoidable variations that occur even in carefully chosen plots, the need of caution in the direct application of preliminary yields to the interpretation of results, and the advantages of the probable error method.

Ten plots were needed to carry out certain experiments in thinning. Great care was taken to find an area where the trees were to all appearances the most uniform. The land was practically level, and no great differences were apparent in soil and drainage.

Fifteen plots of five acres each were selected in rubber planted in November, 1911, and the average diameter of each was secured by measuring two diagonal rows. From these fifteen plots, ten were chosen ; only plots with approximately equal average diameters being retained.

It was originally intended to keep records of yield for only one month before thinning, but the variations in yield were so great during this period that it was decided to extend it, and the preliminary records were continued for ten months (April, 1916 — January 1917).

The trees were already being tapped on the following system, — one lefthanded cut, on 1/3 of the circumference, on a 40 degree angle, and daily tapping. Each plot was tapped by one coolie. On the 2nd and 17th of the month the coolies were changed in a systematic manner, so that after a five-month period each coolie had tapped each plot for a half-month period. In actual practice it was necessary to replace certain of the tappers because of sickness or poor work. In no case, however, did any one coolie tap a plot for more than two half-month periods during the ten months. The latex from each plot was coagulated daily with acetic acid, the coagulum was run through hand rollers, labelled and hung up to dry. These sheets with lump and cup scrap were sent to the Factory Laboratory twice a month, where the dry weight of rubber by plots was determined.

The record of yield in pounds per month by plots, as well as the probable error of the monthly yield for the different months, is given in Table IV.

Table IV.

Month	PLOTS											Probable error	
	1	2	3	4	5	6	7	8	9	10	Total	In lbs.	In % of mean
April.	15.4	15.1	16.4	17.6	23.6	17.4	19.8	21.6	24.1	23.3	194.3	2.36	12.2
May.	54.4	67.3	52.4	55.0	60.0	53.1	46.9	51.6	54.7	56.6	552.0	3.67	6.7
June.	113.1	100.1	100.6	91.3	122.7	114.3	97.7	93.2	130.3	117.9	1081.2	8.95	8.3
July.	94.4	93.1	90.7	88.5	89.7	86.3	93.5	87.5	99.4	81.2	894.3	3.57	4.0
Aug.	115.6	117.9	107.9	107.0	118.1	119.0	108.7	117.9	112.5	111.1	1135.7	3.05	2.7
Sept.	125.7	135.6	138.0	144.0	140.9	143.5	135.6	130.3	148.5	136.3	1378.4	4.54	3.3
Oct.	142.8	128.4	140.1	142.5	138.5	133.8	136.8	130.7	138.3	136.4	1368.3	3.18	2.3
Nov.	86.8	79.0	69.4	81.5	70.7	90.7	69.7	70.3	78.5	78.7	775.3	5.00	6.5
Dec.	92.0	64.7	61.2	75.3	91.5	80.8	75.9	59.2	73.5	89.6	763.7	7.95	10.4
Jan.	113.0	77.6	75.9	69.1	60.1	89.6	86.8	75.8	76.8	113.6	838.3	11.26	13.4

This shows the wide monthly variations in yield that have occured over a ten-month period in these ten plots treated similarly. This is seen best by examining the yield of any two plots over monthly periods. For example, in September plot 1 furnished 125 pounds of rubber and plot 2, 135; while in October plot 1 furnished 142 pounds of rubber and plot 2, 128. If the yield of plot 1 is taken as 100 in each of the months, September and October, then the yields of plot 2 for these months are 108 and 90 respectively. This brings out clearly the danger of comparing results over short periods without making allowance for such variations. From the last two columns it is seen that the variation is much greater at certain times of the year. The percentage probable error appears to increase with a decrease in yield (see table IV). In April, May, November, December, 1916 and January, 1917 when the yields were low, the variation was more marked than in the remaining months.

In order to ascertain whether these variations tend to even up as the period lengthens, the yields of the plots to the end of the 2nd, 3rd, ... 10th month are given in Table V.

Table V.

Period	PLOTS.											Probable error	
	1	2.	3	4	5	6	7	8	9	10	Total	In lbs.	In %
2-month period	69.8	82.4	68.8	72.6	83.6	70.5	66.7	73.2	78.8	79.9	746.3	4.6	5.5
3-month period	182.9	182.5	169.4	163.9	206.3	184.8	164.4	166.4	209.1	197.8	1827.5	11.5	6.3
4-month period	277.3	275.6	260.1	252.4	296.0	271.1	271.1	247.9	253.9	308.5	2721.8	13.23	4.8
5-month period	392.9	393.5	368.0	359.4	414.1	399.1	356.6	371.8	421.0	390.1	3857.5	14.60	3.8
6-month period	518.6	529.1	506.0	503.4	555.0	533.6	492.2	502.1	569.5	526.4	5235.9	14.98	2.9
7-month period	661.4	657.5	646.1	645.9	693.5	667.4	629.0	632.8	707.8	662.8	6604.8	16.71	2.6
8-month period	748.2	736.5	715.5	727.4	764.2	758.1	698.7	703.1	786.3	741.5	7379.5	18.68	2.6
9-month period	840.2	801.2	776.7	802.7	855.7	838.9	774.6	762.3	859.8	831.1	8143.2	24.94	3.0
10-month period	953.2	878.8	852.6	871.8	915.8	928.5	861.4	838.1	936.6	944.7	8981.5	28.40	3.2

An examination of this table shows that there is a reduction in variation as the period is extended up to 6 months, beyond which there are comparatively small fluctuations. From a study of these figures it appears that a five-month period or longer will reduce the probable error of these plots below 4 $^0/_0$, and, even with a longer period, there is no justification for using an appreciably lower probable error.

In order to test the applicability of a probable error of 4 $^0/_0$ for a five-month period. Table VI giving yields and probable errors for these plots, based upon five-month periods was made.

Table VI.

Periods	PLOTS											Probable error	
	1	2	3	4	5	6	7	8	9	10	Total	In lbs.	In $^0/_0$
April, May Juni, July August.	392.9	393.5	368.0	359.0	414.1	390.1	356.6	371.8	421.0	390.1	3857.5	14.60	3.8
May, June July, Aug. Sept.	503.1	514.1	489.7	485.8	531.3	516.1	472.5	480.5	545.4	503.2	5062.0	16.34	3.3
June, July Aug. Sept. Oct.	591.4	575.1	577.3	573.4	609.8	596.9	562.5	559.7	629.0	582.7	5858.0	14.34	2.5
July, Aug. Sept. Oct. Nov.	565.2	554.0	546.2	563.6	557.9	573.4	534.5	536.7	577.2	543.7	5552.0	9 99	1.8
Aug. Sept Oct. Nov. Dec.	562.8	525.7	516.6	550.4	559.7	567.9	526.9	508.4	551.3	552.1	5422.0	14.10	2.6
Sept. Oct. Nov. Dec. Jan.	560.3	485.3	484.6	512.4	501.7	538.4	504.8	466.3	515.6	554.6	5124.0	20.84	4.1

This shows that within the ten months a probable error of 4 $^0/_0$ is applicable te any period of five months. If records over a longer period were available, this probable error might not apply to a five-month period including more of the wintering months during which the yield is reduced, as, for example, the five-month period December — April. It may be seen from Table II that, with a probable error of 4$^0/_0$, the difference, before definite conclusions may be drawn, must amount to 4 × 3.81, or 15.2$^0/_0$, if it is expected in only one direction, and to 4 × 4.51, or 18.04$^0/_0$, if it may be obtained in either direction.

We should, however, be able to interpret experiments in rubber where the difference in results is as low as 5$^0/_0$, as can well occur between two tapping systems.

This would require, with a probable error of 4 %,

$$\frac{4}{\sqrt{n}} = \frac{5}{4.51}$$

$n =$ 13 duplications, if the difference may be obtained in either direction.

and $$\frac{4}{\sqrt{n}} = \frac{5}{3.81}$$

$n =$ 11 duplications, if the difference is expected in only one direction.

Apart from the use of preliminary records in establishing a probable error, their direct application to the interpretation of results may now be considered.

Table VII shows the relative yields by months for these ten plots.

Plot 10 is taken as 100, as it had been selected as the control when the experiment was originally planned.

Table VII.

Month	PLOTS									
	1	2	3	4	5	6	7	8	9	10
April	65.9	64.9	70.2	75.6	101.4	74.4	85.1	92.5	103.2	100
May	96.0	118.8	92.5	97.0	105.9	93.7	82.7	96.0	96.5	100
June	95.9	84.1	85.2	77.3	104.0	96.0	82.8	89.0	110.5	100
July	116.2	114.0	111.8	109.0	110.5	106.3	102.9	107.4	122.4	100
August. . . .	103.9	106.0	97.1	96.3	106.2	107.0	97.8	106.1	101.2	100
September . .	92.1	99.5	101.1	105.8	103.3	105.2	99.5	95.7	109.0	100
October . . .	104.5	94.2	102.8	104.4	101.5	98.0	100.1	95.8	101.5	100
November. . .	110.0	100.2	88.2	103.5	90.0	115.2	88.6	89.4	99.8	100
December. . .	102.5	72.2	68.3	84.0	102.0	101.5	84.6	66.1	82.0	100
January . . .	99.6	68.4	66.8	60.8	52.8	78.9	75.5	58.2	67.6	100

It is seen that there are wide variations in the monthly yields, for example, plot 9 varies from 122 % of plot 10 in July to 67 % in January.

Table VIII shows the relative yields to the end of the 2nd, 3rd ..... 10th month.

Plot 10 = 100.

Table VIII.

Period	PLOTS									
	1	2	3	4	5	6	7	8	9	10
2-month period	87.4	103.1	86.2	90.9	104.7	88.3	83.6	91.7	98.7	100
3-month period	92.5	92.3	85.8	82.9	104.5	93.4	83.2	84.2	105.8	100
4-month period	97.9	98.8	93.4	90.5	106.2	97.0	88.8	91.0	110.8	100
5-month period	100.6	100.8	94.3	92.1	106.1	99.9	91.4	95.2	107.9	100
6-month period	98.5	100.5	96.2	95.6	105.5	101.3	93.5	95.5	108.1	100
7-month period	99.8	99.2	96.0	96.0	104.5	100.5	95.0	95.5	106.8	100
8-month period	100.8	99.3	96.4	98.1	102.9	102.1	94.2	94.8	106.0	100
9-month period	101.1	96.4	93.5	96.7	103.0	100.8	93.2	91.8	103.3	100
10-month period	102.0	93.2	90.3	92.4	97.2	98.3	91.4	88.8	99.4	100

The variations do not show the tendency to become constant which might be expected with a lengthening period. A constancy may however be attained in a longer period than ten months. Such a period will contain at least a complete cycle of periodic variations, and, because of seasonal changes, it would not be less than one year. Records over several years would be required to decide this point definitely. Before preliminary records of yields can be applied to assign relative yielding powers to plots, it is necessary to establish the minimum period for which these records should be kept.

The danger of using preliminary records for short periods to interpret the results of experiments is brought out in table IX.

Table IX.

Actual yields and relative yields (plot 9 = 100) for two successive five-month periods.

Period		PLOTS									
		1	2	3	4	5	6	7	8	9	10
April to May	Actual yields lbs.	393	394	359	359	414	490	356	372	421	390
	Relative yield % of plot 9.	93	94	88	85	99	93	85	88	100	93
Sept. to Jan.	Actual yields lbs.	560	485	485	512	502	538	505	466	516	555
	Relative yield % of plot 9.	109	94	94	99	97	104	98	91	100	108

Let us suppose that the records for the first five months had been kept with the object of carrying out experiments on different methods of treatment during the second five months.

The common practice is to select the highest yielding plot as a control. If a plot gives, after treatment, a yield exceeding that of the control, it is then inferred that at least the excess above the control is due to treatment. Conclusions have been drawn even where the yield of the treated plot did not actually exceed the control, but approached more closely to it than in the preliminary records.

In applying the common practice to the above records plot 9 becomes the control, and, for the sake of easy comparison, is taken as 100. If the results of the second five months had been obtained after treatment, the conclusion would have been drawn that plots 1, 6 and 10 had increased their yields, as a result of the treatment received, at least 9, 4 and 8 % respectively and significance might has been attached to the relative increases in yield of certain of the other plots. Conclusions have been drawn, and published, from differences as low as 5 %. Our results show that a large difference is obtainable if no treatment has been applied. No less than four plots have shown increases, relative to the control, of 13 % to 16 %.

Had a probable error of 4 % been applied to these results, no valid conclusions could have been drawn, unless the difference from the control had exceeded 16 %.

Even if it happens to be correct to infer that treatment has caused a difference, the amount may be wrongly estimated; for instance, in plot 1, if a difference of 10 % from the control were obtained after treatment, only 1 % could be due to the treatment. Costly mistakes may be a result of such incorrect inferences; as for example, where the experiment was planned to test the value of a certain manure, and the cost of the manure were not recovered unless it caused an increase of at least 5 % in the yield. In other words, if the probable error of the experiment is 4 %, as in the above records, a difference of 16 % must be exceeded, before it can be safely concluded that the manuring has had *any* effect, and 21 % to justify the conclusion that the manuring would pay. This may seem, and indeed is, a large difference to obtain in any experiment, but the illustration applies to an experiment where only two plots are compared, as has been commonly the case in field experiments with rubber. Reliable conclusions can be based on much smaller differences, if there are sufficient duplications of the experiment. In this instance if there were 11 duplications, it could be definitly said that any difference beyond 5 % was due to manuring.

It must be remembered that the above data were obtained from comparatively young rubber and the relative magnitudes of the variations may or may not be the same in older rubber.

The preceding discussion does nevertheless, indicate, in our opinion, the advantages of applying a probable error, and the need of exercising considerable caution in the use of preliminary records.

B. PROBABLE ERROR IN TAPPING EXPERIMENTS ON SOENGEI SIKASSIM, SOENGEI BALEH AND GOERACH BATOE ESTATES.

An example is now given in which the probable error method is applied to facilitate correct interpretations of the results of 26 tapping experiments run in triplicate by the Holland American Plantations Company.

For each system of tapping there were three plots of 100 trees each. These plots were situated on three estates — Soengei Sikassim, Soengei Baleh and Goerach Batoe. Three plots for each experiment, or 78 100-tree plots in all, are therefore available.

Obviously the yields from the 78 plots cannot, because of differences in treatment, be combined directly to secure the probable error, so the first method of arriving at the probable error does not apply. There remains the second or "percentage of mean" method of arriving at the probable error. This presupposes that the average or mean of duplicate plots under the same treatment will closely approximate, at least in the greater number of cases, the true or theoretical mean, so that it is justifiable to take the average in each case as the same, namely 100. In this case the chances of the actual average being the theoretical one are reduced, because the three plots although given the same treatment are not true duplicates, as might be assumed on a superficial inspection, since they are not under as nearly similar conditions as possible, but are situated on three estates varying greatly in site conditions. As has been shown previously this tends to secure a probable error which is too low.

On the other hand, by taking the three plots on different sites there is a tendency to secure a larger probable error than would exist on any one estate, and it is the comparison between plots on the same estates that we wish to make. If we assume that the probable error secured by the percentage of mean method is more than the probable error between plots on any one estate, then the probable error so obtained is applicable to the results of the tapping experiments, although it may possibly be larger than is necessary.

The relative yields of the 78 plots for 1915, 1916 and 1915-16 were calculated by the "percentage of mean" method. Those for 1915-16 were plotted as a frequency curve (see plate 1). This curve was symmetrical and showed that the method of least squares was applicable. The probable errors for the periods 1915, 1916 and 1915-16 were then calculated. The detailed figures are shown in Table X.

Table X.

Probable Error of Yield of Tapping Experiments.

Exp.	Plot. *	Yield during 1915.		Yield during 1916.		Yield over 2 year period.	Mean of experiment for 2 year period.	Per cent of mean of each.			d.			d².		
			Mean.		Mean.			1915.	1916.	'15-'16.	1915.	1916.	'15-'16.	1915.	1916.	'15-'16.
1	1	156	158	258	266	414	424	98.7	97.0	97.7	1.3	3.0	2.3	1.69	9.—	5.29
	2	142		546		388		89.9	92.5	91.5	10.1	7.5	8.5	102.01	56.25	72.25
	3	176		594		470		111.3	110.7	110.8	11.3	10.7	10.8	127.69	114.49	116.64
2	1	88	95	190	186	278	282	92.6	102.2	98.6	7.4	2.2	1.4	54.76	4.84	4.96
	2	86		174		260		90.4	93.6	92.3	9.6	6.4	7.7	92.16	40.96	59.29
	3	112		195		307		117.9	101.9	103.8	17.9	4.9	8.8	320.41	24.01	77.44
3	1	165	183	247	266	412	449	90.2	92.9	91.8	9.8	7.1	8.2	96.01	50.41	67.24
	2	217		256		473		118.5	96.2	105.4	18.5	3.8	5.4	342.25	14.44	29.16
	3	166		296		462		90.7	111.3	103.0	9.3	11.3	3.0	86.49	127.69	9.—
4	1	95	112	148	182	243	294	84.8	81.4	82.7	15.2	18.6	17.3	231.04	345.96	299.29
	2	120		197		317		107.1	108.3	107.8	7.1	8.3	7.8	50.41	68.89	60.84
	3	121		202		323		108.1	110.9	109.8	8.1	10.9	9.8	65.61	118.81	96.04

Exp.	Plot.	Yield during 1915.		Yield during 1916.		Yield over 2 year period.	Mean of experiment for 2 year period.	Per cent of mean of each.			d.			d².		
	*		Mean.		Mean.			1915.	1916.	'15-'16.	1915.	1916.	'15-'16.	1915.	1916.	'15-'16.
5	1	80	$88^{1}/_{3}$	165	153	245	242	90.6	107.9	101.3	9.4	7.9	1.3	88.36	62.41	1.69
	2	84		129		213		95.2	84.4	88.1	4.8	15.6	11.9	23.04	543.36	141.61
	3	101		166		267		114.4	108.5	110.5	14.4	8.5	10.5	207 36	72.25	110.25
6	1	94	101	186	167	280	268	93.0	111.3	104.5	7.0	11.3	4.5	49.—	127.69	20.25
	2	90		136		226		89.2	81.5	84.4	10.8	18.5	15.6	116.64	342.25	243.36
	3	119		180		299		117.8	107.8	111.6	17.8	7.8	11.6	316.84	60.84	134.56
7	1	82	$90^{1}/_{3}$	190	175	272	265	90.8	108.6	102.6	9.2	8.6	2.6	84.64	73.96	6.76
	2	96		156		252		106.3	89.2	95.1	6.3	10.8	4.9	39.69	116.64	24.01
	3	93		178		271		103.0	101.8	102.3	3.0	1.8	2.3	9.—	3.24	5.29
8	1	80	$93^{2}/_{3}$	151	153	231	247	85.5	98.7	93.5	14.5	1.3	6.5	210.25	1.69	42.26
	2	90		129		219		96.0	84.3	88.7	4.0	15.7	11.3	16.—	246.49	127.69
	3	111		179		290		118.4	116.9	117.3	18.4	16.9	17.3	338.56	285.61	299.29
9	1	92	$87^{2}/_{3}$	178	171	270	259	104.9	104.1	104.1	4.9	4.1	4.1	24.01	16.81	16.81
	2	85		136		221		97.0	79.6	85.3	3.0	20.4	14.7	9.—	416.16	216.09
	3	86		199		285		98.0	116.4	110.0	2.0	16.4	10.0	4.—	268.96	100.—
10	1	88	99	168	177	256	276	88.9	95.0	92.8	11.1	5.0	7.2	123.21	25.—	51.84
	2	105		153		258		106.0	86.5	93.5	6.0	13.5	6.5	36.—	182.25	42.25
	3	104		210		314		105.0	118.6	113.7	5.0	18.6	13.7	25.—	345.96	187.69
11	1	88	$78^{2}/_{3}$	186	155	274	234	111.8	120.0	117.1	11.8	20.0	17.1	139.24	400.—	292.41
	2	79		152		231		100.3	98.0	98.7	—.3	2.0	1.3	—.09	4.—	1.69
	3	69		128		197		87.7	82.5	84.2	12.3	17.5	15.8	151.29	306.25	249.64
12	1	103	$126^{2}/_{3}$	233	215	336	341	81.4	108.3	98.6	18.6	8.3	1.4	345.96	68.89	1.96
	2	135		176		311		106.6	81.9	91.2	6.6	18.1	8.8	43.56	327.61	77.44
	3	142		235		377		112.1	109.2	110.7	12.1	9.2	10.7	146.41	84.64	114.49
13	1	89	$91^{2}/_{3}$	183	161	272	256	94.0	113.7	106.1	6.0	13.7	6.1	36.—	187.69	37.21
	2	80		133		213		84.4	82.6	83.2	15.6	17.4	16.8	243.36	302.76	282.24
	3	115		168		283		121.3	104.3	110.5	21.3	4.3	10.5	453.69	18.49	110.25
14	1	88	$106^{1}/_{3}$	168	165	256	272	82.6	101.8	94.1	17.4	1.8	5.9	302.76	3.24	34.81
	2	80		118		198		75.2	71.5	72.8	24.8	28.5	27.2	615.04	812.25	739.84
	3	151		211		362		142.0	127.8	133.1	42.0	27.8	33.1	1764.—	772.84	1095.61
15	1	76	$88^{2}/_{3}$	161	144	237	232	85.7	111.8	102.1	14.3	11.8	2.1	204.49	139.24	4.41
	2	105		140		245		118.2	97.3	105.5	18.2	2.7	5.5	331.24	7.29	30.25
	3	85		130		215		95.7	90.3	92.7	4.3	9.7	7.3	18.49	94.09	53.29
16	1	84	88	162	144	246	232	95.4	112.5	106.0	4.6	12.5	6.0	21.16	156.25	36.—
	2	71		112		183		80.6	77.8	79.0	19.4	22.2	21.0	376.36	492.84	441.—
	3	109		159		268		123.9	110.5	115.5	23.9	10.5	15.5	571.21	110.25	240.25
17	1	78	$89^{2}/_{3}$	174	155	252	245	86.8	112.2	102.8	13.2	12.2	2.8	174.24	148.84	7.84
	2	99		148		247		110.1	95.5	100.8	10.1	4.5	—.8	102.01	20.25	6.64
	3	92		143		235		102.5	92.3	96.0	2.5	7.7	4.0	6.25	59.29	16.—
18	1	65	80	114	121	179	201	81.3	94.2	89.0	18 7	5.8	11.0	349.69	33.64	121.—
	2	87		105		192		108.7	86.8	95.5	8.7	13.2	4.5	75.69	174.24	20.25
	3	88		144		232		110.0	119.0	115 4	10.0	19.0	15.4	100.—	361.—	237.16
19	1	82	$105^{1}/_{3}$	147	170	229	276	77.8	86.5	83.0	22.2	13.5	17.0	492.84	182.25	289.—
	2	98		168		266		93.0	98.9	96.4	7.0	1.1	3.6	49.—	1.21	12.96
	3	136		196		332		129.2	115.2	120.1	29.2	15.2	20.1	852.64	231.04	404.01
20	1	137	$141^{2}/_{3}$	235	246	372	387	96.7	95.5	96.1	3.3	4.5	3.9	10.89	20.25	15.21
	2	162		261		423		114.4	106.0	109.3	14.4	6.0	9.3	207.36	36.—	86.49
	3	126		241		367		89 0	98.0	94.9	11.0	2.0	5.1	121.—	4.—	26.01
21	1	113	146	174	228	287	374	77.4	76.3	76.8	22.6	23.7	23.2	510.76	561.69	538.24
	2	143		258		401		98.0	113.2	107.2	2.0	13.2	7.2	4.—	174.24	51.84
	3	182		251		433		124.7	110.1	115.8	24.7	10.1	15.8	610.09	102.01	249.64
22	1	153	182	285	311	438	493	84.1	91.6	88.9	15.9	8.4	11.1	252.81	70.56	123.21
	2	199		309		508		109.3	99.4	103.0	9.3	—.6	3.0	86.49	—.36	9.—
	3	194		338		532		106.6	108.6	107.9	6.6	8.6	7.9	43.56	73.96	62.11
23	1	121	138	224	232	345	370	87.7	96.6	93.2	12.3	3.4	6.8	151.29	11.56	46.24
	2	143		227		370		103.7	97.8	100.0	3.7	2.2	—.0	13.69	4.84	—.—
	3	150		244		394		108.6	105.2	106.6	8.6	5.2	6.6	73.96	27.04	43.56

Exp.	Plot. *	Yield during 1915.		Yield during 1916.		Yield over 2 year period.	Mean of experiment for 2 year period.	Per cent of mean of each.			d.			d².		
			Mean.		Mean.			1915.	1916.	'15-'16.	1915.	1916.	'15-'16.	1915.	1916.	'15-'16.
24	1	99	$112^{1}/_{3}$	176	188	275	300	85.9	93.6	90.7	14.1	6.4	9.3	198.81	40.96	86.49
	2	106		190		296		100.7	101.1	101.0	—.7	1.1	1.0	—.49	1.21	1.—
	3	131		198		329		113.4	105.3	108.6	13.4	5.3	8.6	179.56	28.09	73.96
25	1	152	$181^{2}/_{3}$	255	271	407	452	83.6	94.2	90.1	16.4	5.8	9.9	268.96	33.64	98.01
	2	204		259		463		104.0	95.6	99.2	4.0	4.4	—.8	16.—	19.36	—.64
	3	189		298		487		112.3	110.0	111.0	12.5	10.0	11.0	151.29	100.—	121.—
26	1	77	$88^{1}/_{3}$	153	152	230	240	87.2	100.5	95.8	12.8	—.5	4.2	163.84	—.25	17.64
	2	92		144		236		104.1	94 8	98.4	4.1	5.2	1.6	16.81	27.04	2.56
	3	96		158		254		108.7	103.9	105.9	8.7	3.9	5.9	75.69	15.21	34.81
								Mean = 100					Σ d²	14415.22	10719.97	9308.74

* In each experiment, 1 referes to Soengei Sikassim, 2 to Soengei Baleh and 3 to Goerach Batoe.

Period 1915 = $\Sigma d^2 = 14.415.22$ p.e. for 1915 = 9.11 %.
„ 1916 = $\Sigma d^2 = 10.719.97$ p.e. for 1916 = 7.90 %.
„ '15-'16 = $\Sigma d^2 = 9.308.74$ p.e. for '15-'16 = 7.36 %.

$$\text{p.e.} = 0'67 \sqrt{\frac{\Sigma d^2}{n-1}}$$

This shows a probable error of 9.11 % for 1915, 7 90 % for 1916, and 7.36 % for the two-year period. The difference between the probable errors for 1915 and 1916 may be accounted for by one or both of two factors:

(1) There was better supervision of these plots maintained in 1916 than in 1915, with a consequent reduction in manipulation errors.

(2) In 1916 the rubber was a year older; the possibility of different probable errors for different ages of rubber has already been pointed out.

The fact that the probable error for the two-year period was less than that for either year implies that some variations are compensating as the period increases in length.

As we desire to base our conclusions on the yields over the two year period, the question arises as to the degree of reliability that may be placed upon the probable error for this period. It is impossible to work out the probable error of yield for each estate to ascertain whether each is less than the above probable error. An idea of the reliability may, however, be obtained from the average diameters in 1915, when the experiment was started. At that time none of the plots had received treatment, hence the probable error may be calculated for the three estates together by either method and for each individually by the first method. The probable error found by the first method (Table XI) for all plots was 2.77 %, by the second method (Table XII) 2.71 %. This illustrates the tendency for a reduction in the probable error when it is established by the second method. The probable errors established for each estate by the first method were: Goerach

Batoe 1.39%, Soengei Sikassim 1.62% and Soengei Baleh 2.31% (Tables XIII, XIV, XV). The largest probable error between plots on any estate (Soengei Baleh) was considerably below the probable error established for all the plots by the second method, which means that the probable error of 2.71% although lower than the probable error established by the first method, would still be a conservative one to use in drawing conclusions regarding average diameters. It may be reasonably expected that a similar relationship will exist between the probable error yield of the three estates together and that of each individually.

Table XI.

Probable Error of Average Diameter of Plots in 1915 by First Method.
(i. e. results combined directly).

Class	Frequency of class	Frequency of class × size of class	d	d^2	$d^2 \times f$
4.7	1	4.7	.5	.25	.25
4.8	2	9.6	.4	.16	.32
4.9	8	39.2	.3	.09	.72
5.0	8	40.0	.2	.04	.32
5.1	16	81.6	.1	.01	.16
5.2	11	57.2	.0	.0	.0
5.3	10	53.0	.1	.01	.10
5.4	15	81.0	.2	.04	.60
5.5	5	27.5	.3	.09	.45
5.6	5	28.0	.4	.16	.80
	81	421.8			$\Sigma(d^2 \times f) = 3.72$

mean = 421.8 ÷ 81 = 5.2

$$\text{p.e.} = .67 \sqrt{\frac{\Sigma(d^2 \times f)}{n-1}}$$

p.e. = 2.77% of mean.

Table XII.

Probable Error of Average Diameter of Plots for 1915
by the per cent of mean method.

Exp.	Plots	Average D.B.H. of Plots * 1915	Average of three plots	Per cent of mean	d	d²
0	1 2 3	5.2 5.1 5.4	5.23	99.4 97.4 104.3	.6 2.6 5.7	.36 6.78 32.49
1	1 2 3	5.0 5.4 5.4	5.26	95.0 102.6 102.6	5.0 2.6 2.6	25.00 6.76 6.76
2	1 2 3	5 2 5.1 5.3	5.20	100.0 98.0 101.9	0 2.0 1.9	0 4.00 3.69
3	1 2 3	5.1 5.2 5.3	5.20	98.0 100.0 101.9	2.0 0 1.9	4.00 0 3.61
4	1 2 3	5.2 5.1 5.4	5.23	99.4 97.4 104.3	.6 2.6 4.3	.39 6.76 18.49
5	1 2 3	5.2 5.1 5 4	5.23	99.4 97.4 104.3	.6 2.6 4.3	.36 6.76 18.49
6	1 2 3	5.1 4.9 5.3	5.10	100.0 96.2 93.9	0 3.8 6.1	0 14.44 37.21
7	1 2 3	5.2 4.9 5.4	5.16	100.8 94 8 104.6	.8 5.2 4.6	.64 27.04 21.16
8	1 2 3	5.2 5.0 5.6	5.26	98.8 95.0 106.5	1.2 5.0 6.5	1.44 25.00 42.25
9	1 2 3	5.3 5.0 5.6	5 26	100.7 95.0 104.5	.7 5.0 4.5	.49 25.00 20.25
10	1 2 3	5.4 5.1 5.5	5.36	100.6 95.2 104.3	.6 4.8 4.3	.36 23.04 18.49

Exp. 6	Plots	Average D.B.H. of Plots * 1915	Average of three plots	Per cent of mean	d	d²
11	1	5.2	5.16	100.6	.6	.36
	2	4.9		94.9	5.1	26.01
	3	5.4		104.5	4.5	20.25
12	1	5.0	5.16	96.8	3.2	10.24
	2	5.1		98.7	1.3	1.69
	3	5.4		104.5	4.5	20.25
13	1	5.1	5.10	100.0	0	0
	2	4.8		94.2	5.8	33.64
	3	5.4		105.9	5.9	34.81
14	1	5.1	5.13	99.4	.6	.36
	2	4.7		91.6	8.4	70.56
	3	5.6		109.1	9.1	82.81
15	1	5.2	5.16	100.6	.6	.36
	2	4.9		94.9	5.1	26.01
	3	5.4		104.5	4.5	20.25
16	1	5.1	5.13	99.4	.6	.36
	2	4.8		93.5	6.5	42.25
	3	5.5		107.2	7.2	51.84
17	1	5.0	5.26	95.0	5.0	25.00
	2	5.3		100.7	.7	.49
	3	5.5		104.6	4.6	21.16
18	1	5.3	5.30	101.0	0	0
	2	5.1		96.3	3.7	13.69
	3	5.5		103.8	3.8	14.44
19	1	5.1	5.13	99.4	.6	.36
	2	5.3		97.4	2.6	6.78
	3	5.3		103.3	3.6	10.89
20	1	5.3	5.30	100.0	0	0
	2	5.4		101.9	1.9	3.61
	3	5.2		98.2	1.8	3.24
21	1	5.3	5.26	100.7	.7	.49
	2	5.1		97.0	3.0	9.00
	3	5.4		102.6	2.6	6.76
22	1	5.1	5.16	98.8	1.2	1.44
	2	5.0		96.8	3.2	10.24
	3	5.4		104.5	4.5	20.25
23	1	5.2	5.23	99.3	.7	.49
	2	5.1		97.5	2.5	6.25
	3	5.4		103.2	3.2	10.24

Exp. 6	Plots	Average D.B.H. of Plots * 1915	Average of three plots	Per cent of mean	d	d^2
24	1	5.3	5.23	101.3	1.3	1.69
	2	4.9		93.6	6.4	40.96
	3	5.5		105.1	5.1	26.01
25	1	4.9	5.13	95.5	4.5	20.25
	2	4.9		95.5	4.5	20.25
	3	5.6		109.1	9.1	82.81
26	1	5.0	5.16	96.8	3.2	10.24
	2	4.9		94.9	5.1	26.01
	3	5.6		108.4	8.4	70.56

$\sum d^2 = 1307.09$

$$\text{p.e.} = .67 \sqrt{\frac{\sum d^2}{n-1}}$$

$$\text{p.e.} = .67 \times 4.04 = 2.71\,\%.$$

* D.B.H. = Diameter Breast High or $4^1/_2$ ft.

Table XIII.

Class	Frequency of class	Frequency of class × size of class	d	d^2	$d^2 \times f$	
4.9	1	4.9	—.3	—.09	—.09	Soengei Sikassim 1 9 1 5.
5.0	4	20.0	—.2	—.04	—.16	
5.1	7	35.7	—.1	—.01	—.07	
5.2	9	46.8	—.0	—.0	—.0	
5.3	5	26.5	—.1	—.01	—.05	
5.4	1	5.4	—.2	—.04	—.04	

27 139.3 $\sum (d^2 \times f) = .41.$

Mean = $139.3 \div 27 = 5.16.$

p.e. = $0839 = 1.62\%$ of mean.

Table XIV.

Class	Frequency of class	Frequency of class × size of class	d	d^2	$d^2 \times f$	
4.7	1	4.7	—.3	—.09	—.09	Soengei Baleh 1915.
4.8	2	9.6	—.2	—.04	—.08	
4.9	7	34.3	—.1	—.01	—.07	
5.0	4	20.0	—.0	—.0	—.0	
5.1	9	45.9	—.1	—.01	—.09	
5.2	1	5.2	—.2	—.04	—.04	
5.3	1	5.3	—.3	—.09	—.09	
5.4	2	10.8	—.4	—.16	—.32	
	27	135.8		$\Sigma(d^2 \times f) = .78.$		

Mean = 135.8 ÷ 27 = 5.029.

p.e. = 1159 = 2.31% of mean.

Table XV.

Class	Frequency of class	Frequency of class × size of class	d	d^2	$d^2 \times f$	
5.2	1	5.2	—.2	—.04	—.04	Goerach Batoe 1915.
5.3	4	21.2	—.1	—.01	—.04	
5.4	12	64.8	—.0	—.0	—.0	
5.5	5	27.5	—.1	—.01	—.05	
5.6	5	28.0	—.2	—.04	—.20	
	27	146.7		$\Sigma(d^2 \times f) = .33.$		

Mean = 146.7 ÷ 27 = 5.43.

p.e. = .0755 = 1.39% of mean.

It is, therefore, concluded that the probable error of 7.36 %, established for the yield of these plots by the second method, may be applied with a reasonable degree of safety to these experiments although it could not be used as a standard probable error for rubber. It is a probable error for these plots under the conditions that existed during the two-year period.

To be conservative, and for convenience, the probable error for yield of the period 1915-1916 is increased from 7.36 to 7.5 %.

Therefore, in these experiments a difference of 7.5 % × 1.41 or 10.57 % between plots would be necessary to give even chances in the absence of duplications. These odds apply when a difference may be expected in either direction. If a difference was expected in one direction only, the odds would be 3 to 1 in favor of treatment. As the difference obtained increases, the chances rapidly increase that it is due to treatment; this was shown in Table II. Therefore, these experiments, if odds of 30 to 1 are accepted as giving practical certainty that the difference is due to treatment, a difference between two plots is not conclusive unless it amounts to 4.5 times the probable error, or 34 %, if a difference may be obtained in either direction; or to 3.8 times the probable error, or 29 %, if the difference is expected in one direction only.

We have, however, for each experiment three plots, the results of which can be combined. Therefore, to be conclusive, a difference of 34 % divided by $\sqrt{3}$, or 20 %, would be necessery if a difference may be obtained in either direction, and 24 % divided by $\sqrt{3}$, or 17 %, if the difference is expected in one direction only.

If reference is made to Table X it is seen that the actual average yield for the three plots in experiments 1 and 2 are 424 lbs, and 282 lbs. respectively; i.e. experiment 1 shows a superiority in yield over experiment 2 of 142 lbs or 50 %. As a difference of 20 % is significant, it is concluded that not only does the tapping system of experiment 1 give a higher yield than that of experiment 2, but that a yield at least 30 % greater will be secured by adopting the former.

With the systems in experiments 1 and 3 the actual average yields are 424 lbs. and 449 lbs respectively. The plots of experiment 3 have given 6 % more rubber than those of experiment 1, but no significance can be attached to this difference.

In the same way reliable deductions can be made regarding the differences between any two of the tapping systems.

SUMMARY.

1. In field experimentation with rubber great care must be taken in interpreting results because of natural variations that occur in the yield of equal sized plots of rubber even when similarly treated.

2. Scientific methods must be applied to eliminate these variations and to determine the significance to be attached to differences in results.

3. Previous papers are quoted in which it is shown that normal variations in yields of experimental plots can be allowed for by the use of a single numerical quantity called the „probable error”.

4. The smaller the probable error the greater the degree of precision with which results can be interpreted.

5. Increasing the size of experimental plots beyond a certain limit does not decrease the probable error. Further reduction can only be obtained by duplication of plots.

6. To establish a probable error, records of yields from a large number of similarly treated plots over a period of not less than one year are required. A probable error may also be established from records of a large number of groups of plots, provided that the plots comprising each group have been similarly treated.

7. The minimum size of plot is ascertained by calculating a series of probable errors for plots of various sizes.

8. The peculiarities of the rubber crop may introduce certain inaccuracies if a probable error is to be applied generally. It can only be settled by experimentation whether such inaccuracies are of sufficient magnitude to render inadmissible the application of a standard probable error for rubber.

9. In the absence of a standard probable error, the probable error for a particular experiment can be worked out where duplications exist.

10. WOOD and STRATTON have found that the probable error for annual agricultural crops may be taken as 5 %. It may be inferred, with some degree of confidence, from the experiments discussed above that a probable error for rubber will not be greater than 7.5 % in carefully selected plots each containing at least 100 trees, but more information is required before generalizations can be made.

11. WOOD and STRATTON found 1/80 acre to be the minimum size of plot annual agricultural crops, no definite evidence is available regarding

the minimum size of plot for rubber, but it will certainly be much larger. It may even prove to be several acres.

12. Actual records are given showing the variations which may naturally occur among even the most carefully chosen experimental plots and the danger which may arise in attempting to interpret the results of an experiment, although preliminary records are available, unless a probable error is applied.

13. An example is given of the application of the probable error method to a series of 26 tapping experiments which were carried out in triplicate. They were not planned with the idea of applying the probable error method and present some difficulties; but a good illustration is afforded of how the method can be applied to previous work where duplications exist.

14. Where full advantage is to be taken of results and costly mistakes avoided, field experiments with rubber should be under scientific control.

The authors desire to acknowledge the valuable assistance and advice given by Mr. W. J. GALLAGHER in the preparation of this paper from their original reports.

Technical Department
H.A.P.M.
Kisaran
Asahan
Sumatra E.C.
June 1917.

DE WAARSCHIJNLIJKE FOUT BIJ VELD-PROEVEN MET HEVEA

DOOR

O. F. BISHOP, J. GRANTHAM EN M. D. KNAPP.

Résumé.

Naar aanleiding van vroegere publicatie's van VAN WOOD en STRATTON [1]), PETCH [2]), en van COOMBS en GRANTHAM [3]) wordt in § I een overzicht gegeven van de wijze waarop de resultaten van veldproeven geinterpreteerd behooren te worden, de formules voor de berekening der waarschijnlijke fout nagegaan, en de waarschijnlijke fout bij een bepaald geval uit de opbrengst van 78 vakjes berekend (tabel I), welke in plaat I grafisch zijn voorgesteld. De waarschijnlijke fout blijkt hier 7.5% te bedragen.

§ II geeft een overzicht van de speciale gezichtspunten die zich bij veldproeven met rubber opdoen (groote verschillen tusschen individueele boomen; verandering van omstandigheden in den loop der jaren enz.)

In § III worden deze beschouwingen nader getoetst aan twee groot opgezette tapproeven van de H.A.P.M.

A. Van tien op het oog zeer gelijkmatige vakken van 5 acres elk, werd de opbrengst 10 maanden lang bepaald. De opbrengst in Eng. ponden vindt men in tabel IV; de schommelingen zijn zeer groot, en zoo geeft b.v. vak 1 in September minder, in October meer rubber dan vak 2 enz. Om deze schommelingen te nivelleeren, werden de resultaten van 2, 3, 4, 5 enz. maanden tezamen genomen (tabel V). Het blijkt dat de waarschijnlijke fout bij grootere periodes afneemt, maar bij periodes langer dan 5 maanden vrijwel dezelfde blijft. Tabel VI bevat nu de verschillende periodes van 5 maanden, die men uit de gegevens over 10 maanden kan samenstellen; de waarschijnlijke fout blijft vrijwel dezelfde, n.l. 4%.

De berekening van § I leert nu, dat men bij een waarschijnlijke fout

---

[1]) Journ. of Agric. Science Vol. III part IV (1909).

[2]) Tropical Agriculturist, Febr. 1915.

[3]) Agric. Bull. F.M.S.

van 4 %, slechts met zekerheid conclusie's kan trekken wanneer de proeven verschillen van 15 % of meer geven. Wenscht men al over verschillen van 5 % zekerheid te hebben, dan heeft men 11 herhalingen (parallelveldjes) van de proef noodig.

Tabel VII geeft dezelfde opbrengsten, nu omgerekend door de opbrengst van vak 10 = 100 te stellen; tabel VIII bevat dezelfde omrekening voor de periodes van 2 tot 10 maanden, en het blijkt dat de verhoudingscijfers zelfs bij periodes van 6 tot 10 maanden nog geenszins constant worden.

Tabel IX dient om aan te toonen hoe voorzichtig men moet zijn om uit proeftappingen van slechts enkele maanden conclusie's te trekken. De getallen voor de tweede vijfmaandelijksche periode wijken niet onbelangrijk van die voor de eerste af, en in menige reeds gepubliceerde proef worden uit even groote verschillen conclusie's getrokken, b.v. over den invloed van bemesting of tapsysteem. Het blijkt dat dergelijke conclusie's volstrekt niet gerechtvaardigd zijn.

B. Een tweede voorbeeld leveren proeven met 26 tapsystemen op 3 ondernemingen. Elk vak bevatte 100 boomen. De opbrengsten voor 1915—1916 vindt men in tabel I en plaat I. Tabel X geeft de cijfers voor beide jaren afzonderlijk, met de berekening van de waarschijnlijke fouten, die 9.11 % resp. 7.90 % en voor beide jaren samen 7.36 % bedragen.

De volgende tabellen XI—XV bevatten gegevens over de gemiddelde diameters der boomen en over de waarschijnlijke fouten bij de bepaling hiervan.

De schrijvers komen tot de conclusie, dat bij veldproeven met rubber de resultaten met veel zorg geïnterpreteerd dienen te worden, vanwege de natuurlijke variatie's in opbrengst van gelijk groote veldjes, die op gelijke wijze worden behandeld. Wetenschappelijke leiding is bij dergelijke proeven hoogst gewenscht.

Voor het bepalen van de waarschijnlijke fout zijn opbrengstbepalingen minstens over een vol jaar noodig, tenzij men een zeer groot aantal parallelperceelen neemt. Het is nog de vraag of voor rubber een algemeen geldige waarschijnlijke fout kan bepaald worden; vermoedelijk ligt deze in de buurt van 7.5 %, terwijl men volgens WOOD en STRATTON voor eenjarige gewassen 5 % als waarschijnlijke fout mag aannemen. De grootte der veldjes zal bij rubber belangrijk grooter moeten zijn dan bij eenjarige gewassen, waar men $^1/_{80}$ acre (50 M^2) als minimum aanneemt.

De gegeven voorbeelden toonen aan hoe groote verschillen kunnen optreden tusschen gelijk behandelde veldjes, en hoe onvoorzichtig het is conclusie's te trekken, wanneer de waarschijnlijke fout niet van te voren bepaald is.

UNIVERSITY OF CALIFORNIA LIBRARY
BERKELEY

Return to desk from which borrowed.
This book is DUE on the last date stamped below.

12Mar52BS

29Feb52

JAN 4 1955 LU

21May'57

REC'D LD

MAY 7 1957

27Apr'59BP

REC'D LD

APR 13 1959

LD 21-95m-11,'50 (2877s16) 476

Pamphlet
Binder
Gaylord Bros., Inc.
Stockton, Calif.
T. M. Reg. U. S. Pat. Off.

M43625

HA
29
E5

THE UNIVERSITY OF CALIFORNIA LIBRARY